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On the frozen force between snow and ethylene tetrafluoride resin*

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(Abstract)

Measurements of the coefficient of friction and the frozen forces between snow and ethylene tetrafluoride resin were carried out using a simple shear test in a cold room. From our experiments, the coefficients of static friction were from 0.1 to 0.3, and the coefficients of kinetic friction were from 0.05 to 0.1 in a temperature ranging from 0 to -10℃. The frozen forces corresponding to the maximum shear stress were 1 to 3 kPa under no vertical pressure condition, however, the frozen forces were from 100 to 200 kPa under adding vertical pressure condition and increased slowly with increasing vertical pressure from 25 to 300 kPa. Also, the frozen forces increased slightly with increasing frozen time from 1 to 24 hour and were influenced by surface roughness.

Key words : frozen force, coefficient of friction, snow

I . Introduction

Recently a film material of ethylene tetrafluoride resin has been used as roof of air supported dome in snowy countries. For this application, the frozen force between snow and materials must be known in order to quantify the problems of snow removal.

At melting point of snow, it is important to know the values of the coefficient of static and kinetic friction between snow and roof materials. Meanwhile under condition below the freezing point of water, the frozen force between snow and materials is most important value to removal snowaccretion on various structures.

Wakahama and Mizuno (1979) have obtained the tensile adhesive strength of wet snow onto various kinds of both hydrophilic and hydrophobic materials as a function of free water content of a snow sample ranging from 1.5 to 18 kPa when the snow sample was initially brought to contact with a materials. According to their results, for a heavily wet snow containing free water of 20% or more than 20%, a linear relationship was obtained between adhesive strength and initially given compressive stress.

We conducted the measurements of the coefficient of the friction and the frozen force corresponding to the maximum shear stress between snow and ethylene tetrafluoride resin using a simple shear test and a test machine in a cold room.

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Ⅱ. Experimental methods

A simple shear test was used to determine the coefficient of static and kinetic frictions as shown in Fig.1. The static friction force is given by

$$F_{max} = \mu_0 N . \tag{1}$$

where μ_0 is coefficient of static friction ; it depends on the nature and the state of the surface of the two materials in contact and N is the vertical pressure. Meanwhile, the sliding friction is expressed as the same law of static friction

$$F = \mu N . \tag{2}$$

The coefficient of kinetic friction μ is roughly independent of the velocity, and, like μ_0, a constant depending on the nature of the materials and conditions of the surface. It is universally true that

$$\mu < \mu_0 . \tag{3}$$

We used the snow samples shown in Fig.1 with contact area of 20 cm^2 and the density of snow was 360 kg/m^3. The snow sample on the material was moved at a speed ranging from 0.3 to 0.5 m/s.

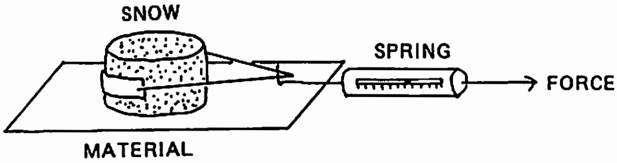

Fig. 1 Simple shear test.

The same method for friction shown in Fig.1 was used to determine the frozen forces under conditions of no vertical pressure. On the other hand, for the measurements of the frozen forces under condition of adding vertical pressure, a plane shear test machine (Seigen Co.;DAT-100 F) was used (Fig.2). In the case, the rate of displacement was 1.0 mm/min in constant and for the snow samples used, contact area was 26 cm^2 and the density of snow was from 500 to 600 kg/m^3.

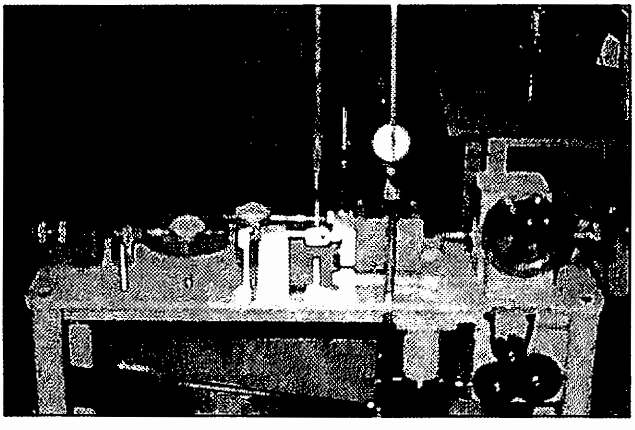

Fig. 2 A plane shear test machine.

Ⅲ. Experimental results

3.1 Friction coefficients

Figure 3 is an example of the relation of the friction coefficients between the snow and a material (M1) in cotact to the temperature, where M1 means an ethylene tetrafluoride resin. Both coefficients of static and kinetic friction incresed with increasing the temperature and the relation of equation (3) is satisfied.

Tusima (1977,1978) has been studied the friction mechanism to explain the low friction on ice and the friction of a steel ball on a single crystal of ice was measured as a function of load, velocity, temperature, and diameter ofslider. He showed that coefficient of kinetic friction between the ice and the steel was very small ranging from 0.005 to 0.2 under very small velocity condition,i.e. 1.5×10^{-7} to 1.8×10^{-3}m/s. His results also showed that the friction strongly increased as the temperature became close to 0 ℃. This agreed with our result shown in Fig.3.

3.2 Frozen force under no vertical pressure

The frozen forces under no vertical pressure were mesured using a simple shear test shown in Fig.1. In this experiment an ice sample with contact area of 24 cm^2 was used. After the bottom of the sample was melted, it was contacted to the materials that have freezed ready beforehand in the cold room. The frozen forces between the ice and two materials,i.e. the resin anda steel, and the frozen time and the temperature under condition of no vertical pressure are respectively plotted in Fig.4 (a) and (b). It was founded that the frozen forces of the resin (M1) were smaller than those of the steel as seen in Fig.4 (a) and

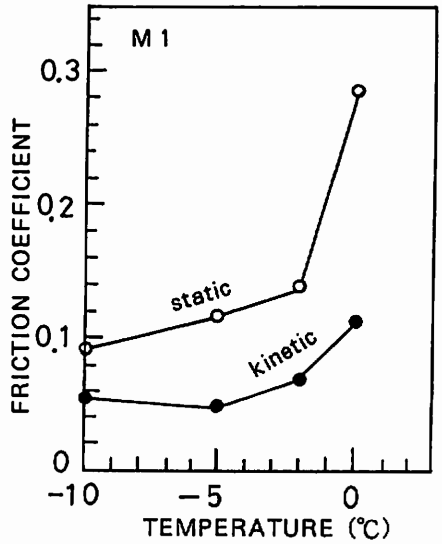

Fig. 3 The relation of friction cefficient to temperature.

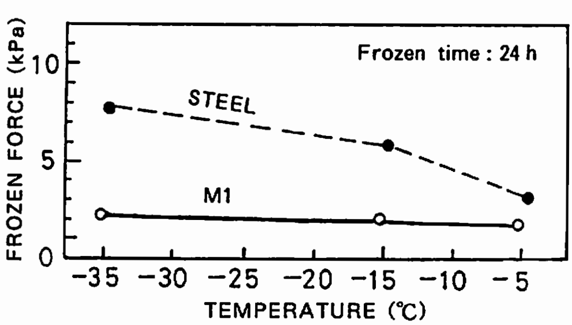

Fig. 4 (a) The relation of frozen force to temperature under no vertical pressure.

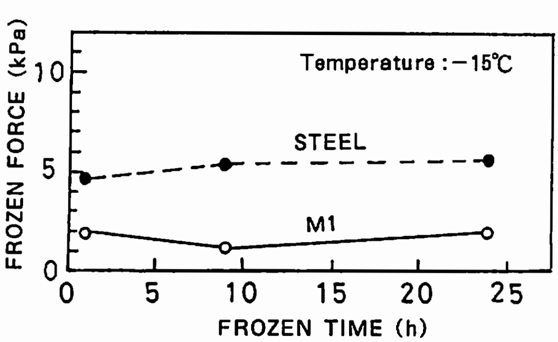

Fig. 4 (b) The relation of frozen force to frozen time under no vertical pressure.

(b). The frozen forces of the resin M1 approximately independent of the temperature. Also, if the sample should be used a snow in this experiment, then the frozen forces must be small thanthose of the ice by becausing of the small contact area in the case of snow samples.

3.3 Frozen force under vertical pressure

At first an experiment has been made on the shear stress with changing of the vertical pressure (0.025, 0.05, 0.1, 0.2 and 0.3 MPa) in the constant temperature of -20℃. Figure 5 shows that relation between the shear stress and the horizontal displacement under constant freezing time (2 hours). In the figure the marks (×) indicate a maximum shear stress that at the point a destruction occurred at the interface between the snow and the material. The maximum shear stress is defined as the frozen force in this study. The relation of the frozen forces to the frozen time under various vertical pressure is shown in Fig.6. From the figure the frozen forces slightly increased with increasing the frozen time, and the values under higher vertical pressure were larger than those under lower vartical pressures because the contact area will be increased as the vertical pressure increased.

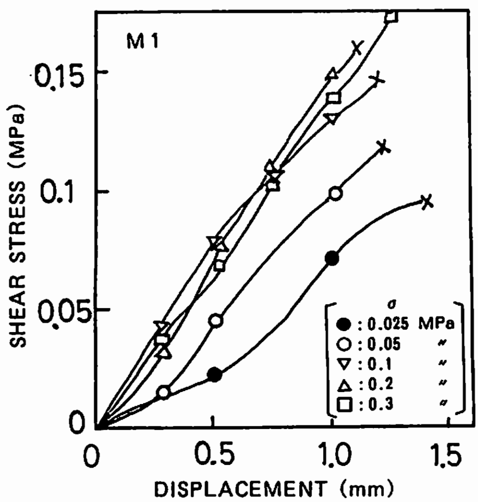

Fig. 5 The relation of shear stress to horizontal displcement under various adding vertical pressures.
× : Snow is broken at interface between snow and material.

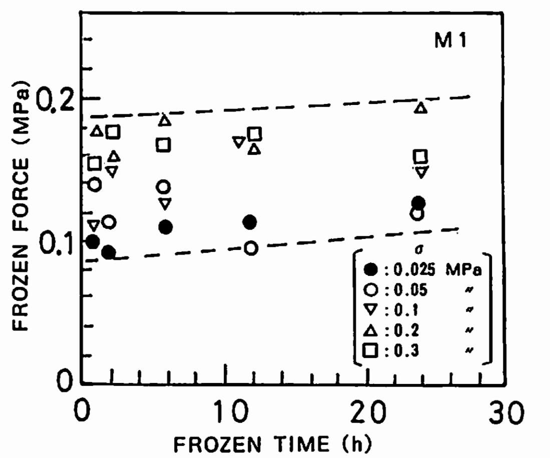

Fig. 6 The relation of frozen force to frozen time under various adding vertical pressure.

A plot of the frozen forces against the vertical pressures for two kinds of resin (M1 and P2) is shown in Fig.7. The two materials are same ethylene tetrafluoride resin, however, P2 was exposured by sun radiation during two months. For the relationship as seen in Fig.7 Mohr-Coulomb's equation (e.g. Jaeger, 1956) is availlable as follows ;

$$T = C - N \tan\phi \qquad (4)$$

where T : the shear stress (frozen force), N : the normal force (vertical pressure), C : the cohesive force, and ϕ : the internal friction angle. In the equation the negative sign is due

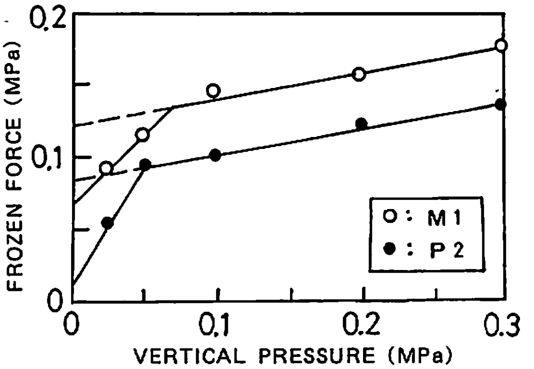

Fig. 7 The relation of frozen force to adding vertical pressure.

Table 1 Cohesive force and internal friction angle concerning to frozen force between snow and materials.

Material	C (kPa)	ϕ (°)
M 1	125	10
P 2	85	9

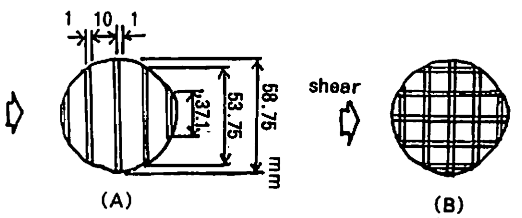

Fig. 8 Dimensions of roughness above surface of materials.
Depth of all streches is 0.5 mm

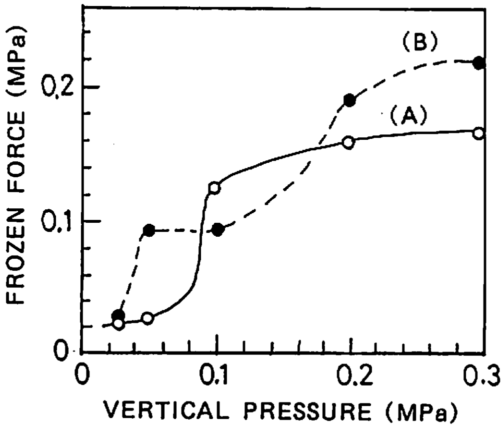

Fig. 9 The relation of frozen force to vertical pressure in the case of rough surface coresponding to Fig.8.

to the convention that N is positive if it is tension. From Fig.7 the constant parameters (C, ϕ) were determined as shown in Table 1.

Next the effects on roughness of the materials have been studied using the material with two type of roughness as shown in Fig.8. The results shown in Fig.9 indicated that the frozen forces were not linear relation on the vertical pressure as like Fig.7. The curves like steps can be explained in terms of chaotic state of the roughness.

Ⅳ. Discussion and conclusion

Measurements of the coefficient of friction and the frozen forces between the snow and the ethylene tetrafluoride resin were carried out using a simple shear test in a cold room. From our experiments following results were obtained :

(1) the coefficients of static friction were the ranging from 0.1 to 0.3, and the coefficients of kinetic friction were more small ranging from 0.05 to 0.1 in a temperature ranging from 0 to -10 ℃ ,

(2) the frozen forces corresponding to the maximum shear stress were 1 to 3 kPa under no vertical pressure condition,

(3) however, the frozen forces were from 100 to 200 kPa under adding vertical pressure condition and increased slowly with increasing the vertical pressure from 25 to 300 kPa,

(4) the frozen forces also increased slightly with increasing the frozen time from 1 to 24 hours, and

(5) the frozen forces were influenced by surface roughness.

Our results, therefore, suggest that if much snow should be deposited on the roof made by the ethylene tetrafluoride resin with low friction, it is very dangerous because a roof snow avalanche should be occurred. Since the snow loads will increase under condition below freezing temperature, therefore, to prevent much depositing snow on the roof we have to heat the back of the roof (Takabayashi et al.,1978 : Morino et al.,1978 ; Kawashima et al.,1978).

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References

Jaeger, J. C., (1956) Elasticity, Fracture and Flow. Methuen, London, pp212.

Kawashima, M., Morino, K. and Takebayashi, Y. (1985) Snow melting on an air-supported dome, №3 Simulation of snow melting. In Proceedings of '85 Cold Region Technology Conference, Sapporo, Japan, 337−340 (in Japanese).

Morino, K., Kawashima, M. and Takebayashi, Y. (1985) Snow melting on an air-supported dome, №2 Required heat for snow melting. In Proceedings of '85 Cold Region Technology Conference, Sapporo, Japan, 331−336 (in Japanese).

Takebayashi, Y., Morino, K. and Kawashima, M. (1985) Snow melting on an air-supported dome, №1 a snow melting experiment on a small scab dome. In Proceedings of '85 Cold Region Technology Conference, Sapporo, Japan, 326−330 (in Japanese).

Tusima, K. (1977) Friction of a steel ball on a single crystal of ice. J. Glaciology, **19**, 225−235.

Tusima, K. (1978) Anisotropy of the kinetic friction on a single crystal of ice. J. Glaciology, **21**, 661−668.

Wakahama, G. and Mizuno, Y. (1978) Studies on tensile strength of wet snow. In Snow Removal and Ice Control Research, National Academy of Science, Special Report 185, 18−22.